United States
Department of
Agriculture

Forest Service

Technology &
Development
Program

3400 FPM
October 1994
9534-2807-MTDC

DGPS Navigation Systems for Agricultural Aircraft in Forestry: *Test Plan*

GPS Aircraft Navigation Test Plan

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August 2, 1994

Final Draft

I. Introduction

The field of Global Positioning System (GPS) based navigation is rapidly growing with technology currently available which can positively impact the effectiveness of USDA-Forest Service Forest Pest Management (FPM) operations. This technology is based on the receipt of signals from a constellation of satellites. These satellites were originally intended for military use but as time goes on, the capabilities of civilian technology based on GPS are increasing rapidly.

Currently, instrumentation using the signals from this satellite constellation can yield positions on the surface of the Earth with less than 2m absolute error under optimal conditions. The applications of this type of accurate positioning are numerous. Of great interest to FPM (investigation and implementation of this technology has been noted as a priority by the National Spray Model Advisory Steering Committee, the Steering Committee for Gypsy Moth and Eastern Defoliators, and many other groups within the USDA-Forest Service) is the ability to accurately know and log to a stored file the exact position of an aerial or ground spray system during an application event. This ability can eliminate the problem of treating the wrong area making flagmen and block marking unnecessary in most cases. Questions raised in litigation can be directly addressed with detailed records. Lost pilot time due to finding home can be reduced, costs associated with returning to base for reloading and then returning to the exact position application ceased can be reduced and misses or gaps can be spotted immediately by the applicator or operational manager allowing corrective action to be taken. In general, costs can be lowered, safety improved and efficiency increased if GPS navigation systems were integrated into FPM pesticide application operations.

II. Problem Statement

There are two distinct sets of problems from the standpoint of FPM regarding GPS navigation technology. The first problems are technical concerns. The primary one is whether the signal can be reliably received by aircraft operating in mountainous or complex terrain. GPS navigation equipment is gaining wide acceptance among agricultural aviators, however, they typically work in relatively flat terrain. Much of the FPM application work is carried out under conditions where ground based transmitters which are used to increase the accuracy of the system, would be obscured. Also, in extreme terrain, the aircraft would not 'view' enough satellites to resolve position. Another technical issue is that aerial applicators in complex terrain often fly 'contours' instead of straight swaths. The shape of the contours is determined by the local terrain. This type of application requires a higher level of sophistication in the associated GPS software and control systems. Further technical concerns are associated with operator safety and workload. If the systems are properly designed, safety should be improved and workloads reduced compared to current operational methods.

The second set of problems involves the acceptance and integration of this technology into the current modus operandi. Various field trials have demonstrated that this technology can provide the positional accuracy claimed for it (Mierzejewski 1993, Sampson 1993, Falkenberg et al. 1994, among others). Beyond the specific technical questions listed above, most of the basic technical concerns have been addressed. However, a critical part of this program is to provide a demonstration of this technology in order to provide a clear rationale and justification (assuming the remaining technical issues can be adequately resolved) for FPM to move forward and implement GPS based aircraft navigation.

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III. Objectives

The objectives of this study are:

A. To identify and resolve the remaining major technical issues with regard to the use of this technology in FPM operational environments.

i. Are there enough satellites visible in complex terrain (as viewed from the spray aircraft) to provide accurate positional information?

ii. Can the real time differential data link be maintained and what is the necessary update frequency?

B. To transfer GPS technology into operations.

i. Evaluate safety issues. This may involve development of innovative approaches since some unique and more stringent safety concerns exist in aerial operations in complex terrain.

ii. Demonstrate that cost and pilot workloads are reduced by this technology in FPM operational environments.

IV. Background

The U.S. Department of Defense (DOD) has been involved in building and deploying a constellation of satellites to be used in military operations over the past decade. The full constellation of 24 satellites was not deployed until 1993. Due to security concerns, DOD has been opposed to civilian use of the full system capabilities. Therefore, the DOD implemented a policy of selective availability (SA) where the signal is intentionally degraded so that the GPS positioning available to the civilian community at large has an accuracy of better than 100m in horizontal positioning as opposed to 15m available to the military. SA is achieved by purposely effecting the signal timing (dither) which introduces a fluctuating error in the indicated position. Thus, using the raw GPS signal, a civilian recipient would not know exactly how far off of an absolute position the indicated position actually is at any given time.

The civil community responded to SA by developing a differential system which eliminates the SA error and increases the positional accuracy to the 2-5m level. This is accomplished by placing one receiver at a point of known location (called a base station). From the base station data, the range corrections necessary to make the receiver's determined location coincide with the known location of the point are calculated. These corrections are then applied to the coexistent data from other receivers (called rovers), thereby producing accuracies of 2-5m. This technique is known as differential GPS (DGPS), and can be done in real time or as post-processing. DGPS is currently allowed by DOD and exceeds the accuracy of the uncorrected military (P-code) signal.

Over the past three years, the GPS and DGPS technologies have begun to positively impact the agricultural aviation industry. The immediate cost savings and reduction in human exposure realized by the elimination of flagmen made this technology very attractive. Also, as environmental concerns increase, the ability to accurately control where application is performed and the ability to provide documentation based on automatically stored computer records in cases of litigation have proved important. The present state-of-the-art allows a differentially corrected GPS signal to be received at 5Hz (5 per second). This signal is used to guide the pilot along a pre-programmed flight path using a light bar, and is stored with absolute accuracies of 5m or greater. It can be transmitted back to the ground and input as an overlay into geographic information systems (GIS) so an operations manager can actually observe the application in real time on a computer screen. The GIS capability is also valuable in analyzing coverage and efficiency as the record of the operation can be downloaded and input as a spatial overlay into the GIS database and spatial summary statistics can then be calculated. The current technology also allows alarms to sound when an edge is crossed and lights to

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indicate when a specific ground location is below the aircraft. The signals could be used in a control mode to perform spray on/off functions based on position. FPM is also investigating integration of the system with pseudo-real-time drift calculations and/or drift sensors to provide drift alarms. These alarms could alert applicators and operational managers to changes in field conditions during application which raise the risk of off-target drift of pesticides.

V. Test Overview

This section is to provide an overview of the proposed test and demonstration. Phase I involves observation and compilation of the uses and performance of aircraft guidance systems in the spring of 1994. The primary activity in this time frame was in operational gypsy moth suppression projects in the Eastern U.S. Results from other demonstration projects and uses of this technology will also be discussed under Phase I. Lessons learned from Phase I will be incorporated into the Phase II trials which will be performed near Missoula, MT in 1994.

A. Organization

The project is organized into two phases. The first phase will be a data gathering phase. MTDC aided by other FS employees and FS contractors will be present at operational uses of GPS navigation systems in Gypsy Moth eradication projects in the eastern U.S. The technical observers will be briefed on the objectives of the data gathering and will be provided with a list of standard questions to be answered regarding the specific program. The purpose of Phase I is to see the various systems in operation under various circumstances. The performance of the systems will be reviewed and any problems that impacted the spray project will be noted. Reports from the observation teams will be compiled into a Phase I interim report produced by MTDC.

Phase II will be an evaluation of the GPS equipment in complex terrain. The object will be to define the accuracy and performance of various GPS systems under actual spraying conditions. The evaluation has been advertised in the Federal CBD and any respondants will be offered the chance to demonstrate the performance of their GPS aircraft navigation system under test conditions specified in this plan. Feedback from Phase I will be used to focus on specific system problems revealed under operational conditions. At the completion of Phase II a full project report including guidance on system capabilities and operating procedures will be compiled by MTDC and we will seek publication in a GPS trade journal to achieve transfer of information outside the FS.

B. Phase I

Phase I was designed to be an observation and data gathering phase. This phase has been completed except for report preparation. Bill Kilroy of MTDC has observed GPS aircraft navigation use in Washington, Michigan and Arizona. These projects involved the use of three different GPS systems. MTDC is contacting field personnel who were involved in the use of GPS aircraft navigation equipment on operational aerial application projects in the Spring of 1994.

The largest efforts MTDC is being briefed on were conducted in Pennsylvania, Virginia, West Virginia, North Carolina and Arkansas. An interim report is being prepared on the performance of GPS aircraft Navigation systems on these projects. This report will be finalized as a section in the overall project report.

Reports on these projects received at MTDC, both written and verbal, are being compiled and used as a basis for design of the Phase II program. The reports are focusing attention on the system designs and features which are the largest contributors to successful operations. The reports also point out procedural problems regarding purchase and implementation of these systems.

C. Phase II

Phase II will be an evaluation of GPS navigation systems in complex terrain, typical of many pesticide application programs in both the western and eastern U.S.

1. Site

The proposed site is the Ninemile Creek drainage on the Ninemile Ranger District approximately 20 miles west of Missoula, MT on the Lolo National Forest. This site provides terrain typical of pesticide application programs in the western U.S. Two ridges reaching over 7,000′ amsl trend north - south with numerous east west trending finger ridges falling down to around 3500′ amsl. This terrain provides a variety of aspects, geometries and exposures. Also, the district has a dirt runway of approximately 2000′ in length which will be utilized during the positional accuracy portion of the program. There are numerous roads in the drainage which can be used both for marking access as well as observer access. Operational facilities at the Aerial Fire Depot (AFD) in Missoula will be utilized in support of aircraft operations.

2. Operation

The evaluation/demonstration has been advertised in the Consumer Business Daily (CBD). Any manufacturers or operators of GPS systems that desire to participate at no cost to the U.S. Government will be welcome. MTDC will accomodate participants schedules to allow any dates in the month of October, 1994 on a first come, first serve basis. It is envisioned that two days will be required per demonstrator. The first day will be to orient the participant with the trial and the evaluation area. The second day will be to perform the evaluation and allow the participant time to show off any system features that could be of interest to the FS. The participant will be required to supply one pilot, a fixed-wing aircraft and a GPS system. The participant will also be required

to supply one remote differential station. The differential site, site access etc. will be provided by the FS. Note that the differential station will be at a fixed site in all these tests.

3. Responsibilities

Project Oversight and Coordination Harold Thistle/Tony Jasumback

Aircraft Facilities and Coordination Bill Kilroy/George Jackson

Meteorological Monitoring, Differential Station Coordination and Access Mike Huey/Don Lassila

Demonstrator and Observer Accomodation Dave Rising

VI. Equipment Capabilities

The desired equipment capabilites listed here are based on a previous list prepared by Tim Roland of APHIS. This list has been substantially altered to reflect program needs of FPM. The technology requested in this list is known to exist or is thought to be possible as hardware or software extensions to existing technology. The actual equipment used in Phase I was dependent on the outcome of the bid process for the operational spraying programs. Phase I is intended to focus attention on specific logistical concerns, including equipment problems, that will only become evident in an operational environment. Demonstrators considering participation in Phase II should consider the following system capabilities as features that are considered potentially useful in FPM applications.

1. Provide real-time differential GPS guidance with 5 Hz update capabilities and a maximum absolute error of 2-5m. Higher spatial accuracy is desirable.

2. Selectable application patterns with ability to use contours for complex terrain applications.

3. Variable swath width.

4. Data logging capabilities with sampling rates from the basic 5 Hz of the positional signal and lower. Full record includes position, time, altitude, speed, track, application on/off. File labels will include aircraft number, pilot and job name or number. Additional consideration will be given to systems that log wind speed and direction, temperature, relative humidity and flow and/or release rates of the applied material.

5. Capability to log all defining elements of an application job or area.

6. Pre-loaded route capabilities interfaced with a light bar for real-time pilot guidance.

7. Edge indicators to alert pilot when he crosses into/out of specified area.

8. Light bar must be easily visible with optical increments programmable down to 1m.

9. A feature which provides instant range and bearing to home base port.

10. A feature which allows applicator to return to exact point

the application stopped.

11. GPS Guidance System malfunction indicators.

12. The capability to transmit real-time information (essential data elements from 4 and 8) to a second party on the ground.

13. A GIS system integrated so that near real-time information can be displayed during operations at a ground station. This GIS system should be expandable and inclusion of new geographic data bases should be an user friendly and standardized procedure.

14. An easy to read in cockpit display will show swath number, cross track error, true ground speed, total acres sprayed, magnetic heading.

VII. Test Methods

Test 1.

The first exercise will test a given GPS systems ability to accurately log the position of a straightline. This will be accomplished by surveying and marking the runway centerline on the Ninemile District. The survey will be conducted with a survey grade GPS unit which utilizes carrier phase signal processing and is accurate to within centimeters. This should be a straightforward test of the GPS system accuracy and modern GPS aircraft guidance systems should be able to chart a line with accuracy approaching the pilot's ability to fly a straightline. MTDC plans to erect a meteorological tower in the district so that differences in wind conditions (both speed and direction) between trials are known. A video camera at a known position with time marking will film the runway fly-by.

Test 2.

The second part of the quantitative trial will involve hypothetical spray blocks. MTDC will lay out multiple spray blocks in one of the finger drainages on the Ninemile District. The blocks chosen will not contain extreme terrain but will be typical of aerial spray operations in the mountains. The blocks will be positioned using GPS. The test will evaluate the GPS aircraft navigation system ability to fly to the blocks, record the pilot's path during a hypothetical application and the ability to fly a straightline return course.

The primary question to be answered in all of these tests is what percent of the time will the constellation be obscured to the extent that the aircraft position is not accurately known and how will this effect the ability of the pilot to adequately perform the mission. Also, with airspeeds in excess of 75 mph, what is the minimum update frequency which is acceptable. A number of issues beyond basic system accuracy will also be addressed. MTDC will compile a list of safety concerns as perceived by the operators and project managers. Ease of use and the perception of the pilots with regard to system usefulness will be evaluated. Any ideas regarding the achievement of additional accuracy, update speed and/or dependability and other basic performance tests are encouraged and tests suggested by specific participants that can be performed within the cost/time framework of this evaluation will be considered.

All stored data, both numeric and graphical will be reviewed to evaluate whether it meets FPM needs. Also, questions of system flexibility, ease of custom configurations, interfacing with

commonly used geographic and numeric data bases will be answered with regard to the data logger itself and the associated software. This is an area where capabilities offered by different manufacturers can be expected to vary greatly.

Finally, these tests and demonstrations should provide a basis for evaluation of the logistics of implementation on a wider scale. These logistics would include actual equipment costs, changeover costs, recommended hardware and software to interface with these systems for optimal results and training requirements inside and outside FS-FPM to gain maximum advantage of this technology.

VIII. Demonstrations

The equipment demonstrations and the interaction of the participants with FS personnel is a primary objective of this project. Participants are encouraged to show all features of their systems which may be of interest to the FS. Time will be set aside for both aerial demonstrations and lecture/desktop presentations. Observers will be encouraged to discuss the systems and associated technology with participants. These demonstrations will serve the mutually beneficial purposes of getting industry familiar with FS applications and in getting FS personnel familiar with available technology.

IX. Summary

It is expected that GPS navigation technology will impact FPM operations positively in the near future as it has in the wider field of agricultural aviation. This test plan is designed to identify the capabilities, potential and limitations of this technology in FPM applications and also to provide insight into the most effective means of proceeding with development and/or implementation of the technology in FPM operations. To achieve these goals developers and operators are encouraged to participate in the evaluation and demonstrate the state-of-the-art in this important new technology.

References

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